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**Mars Exploration Program**  
**Strategy: 1995-2020**

Donna L. Shirley  
Manager, Mars Exploration Program

and

Dr. Daniel J. McCleese  
Mars Exploration Program Scientist

Jet Propulsion Laboratory  
California Institute of Technology  
4800 Oak Grove Drive  
Pasadena, CA 91109

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## MARS EXPLORATION PROGRAM STRATEGY: 1995-2020

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### Abstract

in the wake of the failure of the Mars Observer mission in 1993, a long-term program of robotic exploration of Mars was established. The themes of the Mars Exploration Program are to understand life, climate, and resources on Mars, with these themes tied together by the common thread of water. The Mars Exploration Program comprises at least one Discovery mission (Mars Pathfinder), the Mars Surveyor Program, plus sample return missions and other missions to prepare for possible human expeditions to Mars. The program will launch (on average) two missions every 26 months. The missions launched between 1996 and 2001 will include a lander and an orbiter at each opportunity, launched on the Delta family of launch vehicles. international participation is an important factor in the program, and relationships are being established with Russia, Europe, and Japan. The program is severely cost constrained, with missions costing about \$150M apiece or less, including launch and operations.

### The "Water Strategy"

The Mars Exploration Program will continue the exploration of the red planet, which has fascinated humankind for thousands of years. Robotic spacecraft began visiting Mars in 1965, and landed on the surface in 1976. Mars was found to be a planet of stark contrasts. The surface features range from ancient, cratered terrain like Earth's moon, to giant

volcanoes and a canyon as long as the United States is wide. The atmosphere is less than 1% as dense as Earth's, but there are constant polar caps with reservoirs of water ice. Close up, Mars resembles an earthly desert like California's Mojave, but there is evidence that water once flowed and cut channels on the surface.

NASA Administrator Dan Goldin and NASA Associate Administrator for Space Science Wes Huntress have agreed on a strategy for the exploration of Mars for the next 10 years. The strategy is to explore and study Mars in three areas:

- Evidence of past or present life
- Climate (weather, processes, and history)
- Resources (environment and utilization)

Mars will be our first foothold in the search for life beyond Earth. We began our search for life on Mars using the tools of astronomy. As we extend our reach with new astronomical tools in search of planets and life in other solar systems, Mars remains our touchstone for understanding planetary evolution different from Earth's. Robots and humans will go to Mars to explore intensively. We seek the markers of life from which we will learn how to find and study hospitable worlds. Using both remote presence and physical contact, our skills will be honed and our reach lengthened sufficiently to understand whether we occupy a unique place in the universe or one of many such places scattered throughout it,

If life ever arose on Mars it would almost surely have been connected with water. And understanding the water-connected processes that led (or didn't lead!) to life on Mars will help us understand the potential for life elsewhere in the Universe. The climate and resources themes are also connected with the search for water on Mars. When and where was water present in the past, and what is its current form and amount? We know from previous missions that the Martian polar caps include water ice as well as frozen carbon dioxide. The Viking and Mariner 9 orbiter images show evidence of past great floods (the Pathfinder lander is planning to land in such an area), and of dry rivers and lake beds. Where did all the water go?

Water is key to climate both on Earth and Mars, and understanding the history of the Martian climate will help us better understand the Earth's climate change processes.

Water will also be a major resource for future human exploration of Mars, and if we understand how Mars evolved (including discovering the sources and sinks of water, past and present) we may be able to locate reservoirs of water for human use.

#### A Series of Missions to Build Up "Water" Knowledge

Our exploration of Mars for greater understanding of life, climate, and resources will focus, in large part, on the study of water and its role in the history of the planet. How do we go about finding out about water on Mars? Dr. Daniel McCleese of JPL, the Mars Exploration Program Scientist, and Dr. Steven Squyres of Cornell, the head of the Mars Science Working Group, led that group to define a strategy for the "water search." They looked at how small Mars orbiters, landers, "networks" of landers, and sample returns could be combined in a logical progression of missions that will build up an understanding of how water has existed and is existing on Mars today.

Small orbiter missions will search for accessible water (we know that ice is accessible at the poles, but are there reservoirs underground or in the soil?). They'll search

for ancient sediments and hydrothermal deposits (dry lake beds and hydrothermal vents). They'll provide data needed to understand the present Martian climate and study how water escapes from the atmosphere into space. The orbiters will also study the surface of Mars and identify good landing sites for the landers, and will provide radio links between the landers and the Earth.

Small lander missions will search for carbonates and evaporites that could only have formed in the presence of water. Landers can investigate water reservoirs in detail; for example, they can measure the amount of water in the soil, or examine the polar ice caps (using drilled core samples and electromagnetic sounding) to see how, when, and how much ice was laid down. Investigation of surface chemistry and how the rocks and soil have "weathered" will tell us about the past climates. And the landers may find organic compounds or even evidence that tells us whether life was ever present on the surface of Mars; and if not, why not.

"Networks" of more than a dozen very small landers scattered over the planet could be used as weather stations to study Martian weather and the circulation of its atmosphere. If the network landers also have seismometers on board, and if they detect "Marsquakes," that information will tell us about what Mars is like deep in its interior, and how the interior has evolved over time. Mobility will be important for understanding the Martian surface and accessing features of particular interest, so missions involving long-range rovers and balloons are being studied.

Finally, sample return missions can bring rocks and soil to laboratories on Earth for analysis by our most sophisticated instruments (too large and massive to send to Mars), which can tell us about the chronology of the planet's evolution, and may even allow us to detect compounds that could have led to life or that are evidence of past life. (The odds of being able to select a rock with a fossil, however, are very low, even if fossils exist on Mars.)

## The Baseline Mission Set

All of these missions must be done within the very tight cost constraints of the Mars Exploration Program. The entire program over the next 10 years will be conducted for about one-third the cost of the Viking missions, which orbited and landed on Mars twenty years ago. Each mission will cost about the same as a major motion picture, and the total cost of the first 10 missions to Mars will be about that of a single major military aircraft.

The Mars Science Working Group laid out a "strawman" strategy for fitting the science goals into a set of missions that can gradually build up our knowledge of Mars over the next 10 years. This set of missions has evolved over the past year to that shown in Figure 1. Figure 1 shows the Mars launch opportunities from 1996 through 2005. The bottom half of the chart is the "US Only" component of the program, while the top half is actual or potential augmentation by international

partners. The "baseline" missions are clear, with possible alternative missions or augmentation shaded. The dollars shown are, respectively, the development cost, operations cost, and approximate launch cost of each year's mission set.

Mars Pathfinder will be the second mission in the series of NASA's Discovery program of planetary exploration missions. It will launch in December 1996 on a McDonnell Douglas IMta117925 rocket (capable of throwing about 1000 kg to Mars). Mars Pathfinder will fly directly to Mars and plunge into the atmosphere at 17,000 mph (27,000 km/h) without going into orbit. Using a combination of a heat shield, parachute, rockets, and airbags, Pathfinder will land on the surface in an ancient flood plain that is expected to be littered with a wide variety of rocks. Pathfinder will image the Martian terrain in 13 different colors, monitor the weather, and deploy a small rover to explore the region around the lander and measure the composition of the surface.

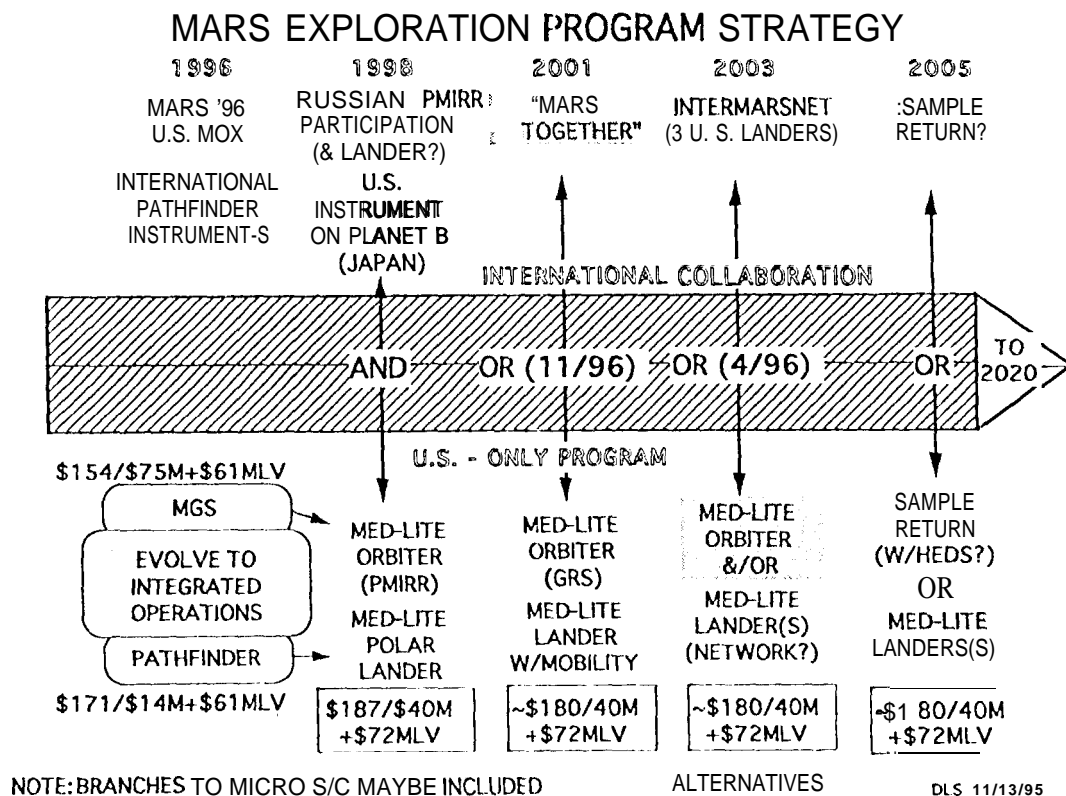


Figure 1. Mars Exploration Program mission set.

Mars Global Surveyor, which will launch in December 1996 (also on a Delta 11 7925), will go into orbit around Mars in September 1997. It will use "aerobraking," skimming through the upper part of the thin Martian atmosphere, to go from a long, looping orbit into a circular polar orbit. Mars Global Surveyor will scan the surface of Mars for a full Martian year (about two Earth years) using 6 of the 8 instruments that were originally flown on Mars Observer (which was lost in 1993 — the first planetary spacecraft failure in 27 years).

Mars Global Surveyor is the first of a series of missions called the Mars Surveyor Program. This program will fly two missions to Mars every opportunity (about every 26 months), and, with Pathfinder, is pioneering the "better, faster, cheaper" approach to planetary missions. Through competitive procurements, Lockheed Martin Astronautics of Denver, Colorado, has been selected as JPL's industrial partner for Mars Global Surveyor, and for at least the subsequent set of Surveyor missions to be flown in 1998.

In late 1998, Mars Surveyor '98 will launch an orbiter and a lander on a Delta 7325 "Med-lite" launch vehicle. (The Med-lite will only throw about 565 kg to Mars, but is expected to cost considerably less than a Delta 7925). The orbiter will carry a Pressure Modulator Infrared Radiometer (PMIRR) to map atmospheric temperature, water vapor, and dust over a full Martian year. This instrument was also previously flown on Mars Observer. The lander launched in 1998 will come to rest near the south pole of Mars and will carry a payload, including a robotic arm, that will excavate Martian history by trenching down through thin layers of dust (and possibly ice) deposited in the layered terrain. The polar lander will also chemically analyze the soil, including a search for organic molecules.

The final element of the lost Mars Observer payload (a gamma ray spectrometer) will search for water in 2001 on the Mars Surveyor '01 orbiter. Also to be launched in '01 is a lander that may explore the ancient highlands of Mars in areas where water is thought to have once flowed. The 2001 lander may analyze rocks to determine the ancient history of the climate and geology of Mars. The 2001 orbiter will be

launched on a Delta 7325, but the lander may be launched on a new "Delta-lite" configuration that will reduce the lander's mass allocation. The 2001 mission may be conducted in partnership with the Russians, with the orbiter being launched on a Russian Molniya. This "Mars Together '01" launch would also include one or more Russian landers. A Russian lander could include a large rover, or perhaps two "small stations" of the Russian Mars '96 mission type.

In 2003, the Mars Surveyor Program is exploring a partnership with the European Space Agency (ESA) to launch three US landers, each lander carrying international payloads. These landers, plus a communication orbiter provided by ESA, would be launched on a European rocket (Ariane 5). This joint NASA/ESA mission is called InterMarsNet. The landers would explore the interior of the planet using seismology to detect "Marsquakes," study geochemistry at three sites, and act as weather stations. In addition, a separate United States mission may be flown, perhaps deploying a "network" of complementary and very small weather stations around the planet,

Mars Surveyor '05 mission may be the first in a series of missions to return samples from the Martian surface. Another possible sample return target is the Martian moon, Phobos. The Russians are especially interested in a Phobos sample return mission. Sample return missions, in general, will probably require violating some of the constraints of the Mars Surveyor program. They may be too expensive to be completely funded by the Mars Surveyor Program, and/or they may require violating the "two-launch per opportunity" rule. Therefore, these missions may be in partnership with the Russians and/or Europeans. A continuing program of robotic missions, including the return of samples, over 10 years or so will pave the way for future human exploration.

### New Technology Infusion

More instruments can be carried, or more landers and orbiters sent, if new technology improvements can be introduced into the US spacecraft to make them smaller, lighter, and

cheaper. The Mars Pathfinder mission has introduced a new flight computer, based on the commercial IBM/Loral RS6000 computer, that will be the basis for the computers of a number of future planetary missions. This provides an enormous increase in computational power. Pathfinder is also utilizing a commercial operating system for its computer, and has pioneered a concurrently engineered flight/ground data system that has greatly reduced costs. Pathfinder has also pioneered a low-cost entry and landing approach, of which all but the final airbag impact system is being baselined for future Mars missions. Mars Global Surveyor is utilizing a composite structure for the spacecraft, although its electronic systems and instruments are inherited from Mars Observer.

A program called "New Millennium" is currently being planned to develop and demonstrate the next generation of space technologies to reduce costs and improve performance for both planetary and Earth missions. The Mars Exploration Program will be a "customer" for this new technology, and some of the New Millennium demonstrations may "piggyback" on Mars missions. For 1998 the feasibility of the Mars Surveyor '98 lander carrying one or two New Millennium "microlanders" to Mars is being studied.

Investment strategies are being developed by the Mars Exploration Program at JPL in partnership with Lockheed Martin, the New Millennium Program, and NASA's Office of Space Access and Technology (OSAT). Technology investment is required to shrink the '01 and '03 landers so that they are compatible with the limitations imposed by the Delta-lite launch vehicle, and the even more stringent limitations of the InterMarsNet mission. With the current InterMarsNet concept the US landers must mass no more than 415 kg each, which means that the landers must decrease 150 kg from the 565 kg in 1998. Key technology advances are required to accomplish this mass reduction, while hopefully maintaining or increasing the payload fraction. These advances center around the electronics: an advanced flight computer and memory, a small deep-space transponder (X-band), lightweight batteries, a high-efficiency solid-state power amplifier, advanced power

electronics, and an inertial fiber optic gyroscope.

In addition, because of the harsh environment on the surface of Mars, technology advances in temperature-tolerant electronics and lightweight insulation are required to enable long-term lander missions. The Pathfinder rover has pioneered an approach to lightweight insulation using silica aerogel; however, phase-change materials are expected to be necessary for future missions.

The Pathfinder landing ellipse is about 70 by 150 km and its rover can only travel a few hundred meters. The lander mission in 2001 is expected to require much more accurate landing (< 50 km landing ellipse) and considerable mobility (tens of kilometers) to enable access to ancient lake beds that may hold clues to the climate history of the planet. Advances in sample collection and storage, and in sample return technology (such as utilization of the atmosphere to manufacture fuel) will be required to enable low-cost sample return by 2005.

#### Preparation for Human Missions

Each of the robotic missions in the Mars Exploration Program will be gathering information needed to plan future human missions to Mars. The robots will find and scout safe and interesting human landing sites, characterize the atmosphere and surface environments so that human missions can be designed properly, look for water and other resources needed by humans, and develop technologies (such as very low mass electronics) that will be important for human space flights to Mars.

Over the next couple of decades the robotic part of the Mars Exploration Program will result in a detailed understanding of Mars, which is of interest not only to scientists but to understanding more about the Earth's environment, and eventually, for future human exploration.

NASA is currently developing a long-range "road map" for the human exploration of Mars. The road map builds upon the capability of the international space station to understand how

people can live and work in space. Trips to Mars will utilize new launch vehicle technologies currently just beginning development, including reusable and expendable rocket-s. The use of commercial technologies such as advanced electronics will greatly reduce the cost of human exploration of Mars. A current goal of this road map is to enable the first human Mars mission in 2018.

Humans on Mars, in partnership with robots, will explore the planet in more detail than robots alone can. Human presence may be required to finally answer the question of whether Mars has or once had life, and humans will seek to understand the implications of the answer to that question for the possibility of life elsewhere in the universe. Humans will utilize the resources of Mars to investigate how the planet can be made more easily habitable for future generations. And finally, our grandchildren may become citizens of Mars.

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